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RESEARCH MEMORANDUM

for the

Bureau of Ordnance, Department of the Navy

PERFORMANCE OF SINGLE-STAGE TURBINE OF MARK 25 TORPEDO

POWER PLANT WITH TWO SPECIAL NOZZLES

II - EFFICIENCY WITH 20°-INLET-ANGLE ROTOR BLADES

By Harold J. Schum and Warren J. Whitney

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

FOR REFERENCE

NOT TO BE TAKEN FROM THIS ROOM

REVIEWED BUT NOT EDITED

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
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SUMMARY

A single-stage modification of the turbine from a Mark 25 torpedo power plant was investigated to determine the performance with two nozzle designs in combination with special rotor blades having a 20° inlet angle. The performance is presented in terms of blade, rotor, and brake efficiency as a function of blade-jet speed ratio for pressure ratios of 8, 15 (design), and 20.

The blade efficiency with the nozzle having circular passages (K) was equal to or higher than that with the nozzle having rectangular passages (J) for all pressure ratios and speeds investigated. The maximum blade efficiency of 0.571 was obtained with nozzle K at a pressure ratio of 8 and a blade-jet speed ratio of 0.296. The difference in blade efficiency was negligible at a pressure ratio of 8 at the low speeds; the maximum difference was 0.040 at a pressure ratio of 20 and a blade-jet speed ratio of 0.260.

The blade efficiency of the unit with nozzles J and K was compared with the blade efficiencies obtained with four other nozzle designs previously investigated in combination with the 20°-inlet-angle rotor blades. The blade efficiency with nozzle J was relatively low, whereas the efficiency with nozzle K was equal to or higher than those with the other nozzles over the range of speeds at pressure ratios of 15 and 20. The maximum difference in blade efficiency ascribable to the nozzle designs was 0.040.

INTRODUCTION

The performance of the turbine from the Mark 25 aerial-torpedo power plant was investigated at the NACA Lewis laboratory at the request of the Bureau of Ordnance, Department of the Navy. Because of the small blade heights and the impracticability of obtaining measurements within the turbine, the only method of evaluating characteristics is a comparative study of over-all performance with various nozzle and rotor configurations. Previous investigations with various nozzle and blade designs are reported in references 1 to 4.

The nozzle-design studies have been continued with two additional nozzles arbitrarily designated J and K. Both nozzles had smaller port cross-sectional areas than those nozzles of similar design previously investigated. The performance of a single-stage unit with nozzles J and K and special 0.45-inch rotor blades is reported in reference 5. In the investigation reported herein, nozzles J and K were operated in combination with rotor blades of standard length (0.40 in.) but an inlet angle of 20° instead of the standard 17° inlet angle.

The performance of the single-stage turbine was determined for constant inlet temperature and pressure of 1000° F and 95 pounds per square inch gage. The turbine was operated at pressure ratios of 8, 15 (design), and 20 over a speed range of 6000 to 18,000 rpm. Indicated turbine power output was corrected for mechanical losses to determine rotor efficiency and for mechanical and windage losses to determine blade efficiency.

APPARATUS AND METHODS

The Mark 25 aerial-torpedo power plant described in reference 1 consists of a two-stage counterrotating impulse turbine employing a 90°-nozzle-arc gas admission. The unit was modified to operate as a single-stage turbine for the investigation reported herein, the apparatus and instrumentation being the same as that described in reference 2 with the exception of the rotor and the nozzles. The rotor blades investigated have an inlet angle of 20° instead of the standard 17°.

Characteristics of nozzles J and K and nozzles A, E, H, and I previously investigated are presented in the following table:

Nozzle	Number of ports	Port-inlet configuration	Cross-sectional shape of port	Total measured throat area (sq. in.)	Measured expansion ratio
A	9	Rounded	Rectangular	0.183	1.47
E	9	Rounded	Circular	.193	1.00
H	9	Sharp-edged	Rectangular	.226	1.12
I	9	Sharp-edged	Rectangular	.217	1.20
J	9	Sharp-edged	Rectangular	.191	1.11
K	8	Sharp-edged	Circular	.153	1.16

Nozzles J and K are shown in figure 1 and are described in reference 5. Nozzle J was run with a 0.030-inch nozzle-rotor axial clearance; nozzle K was operated at 0.040-inch clearance. Reference 3, however, indicates no effect on turbine performance for this increment in clearance.

The precision of the observed measurements is estimated to be within the following limits:

Air flow, percent . . . . ±1.50
Torque, ft-lb . . . . ±0.15
Dynamometer speed, rpm . . . . ±5
Inlet-gas temperature, percent . . . . ±0.25
Inlet-gas pressure, percent . . . . ±0.50
Pressure, in. Hg absolute . . . . ±0.05

The calculation methods are given in references 1 and 2.

RESULTS AND DISCUSSION

The efficiency data of the Mark 25 turbine modified to operate as a single-stage unit with nozzles J and K and special 20°-inlet-angle blades are summarized in tables I and II, respectively.

Brake efficiency and rotor efficiency are shown in figures 2 and 3, respectively, for the two nozzle-rotor configurations. At a pressure ratio of 8, the brake efficiencies with the two nozzles were practically equal over the speed range, as were the rotor efficiencies; the maximum efficiency difference is less than 0.010. At pressure ratios of 15 and 20, however, both brake and rotor efficiencies for nozzle K were higher than those obtained for nozzle J over the operating range.

The blade efficiency with the two nozzles is shown in figure 4.
Blade efficiency was considered a better criterion of performance
for a given nozzle-blade combination because the effects of mechan-
ical friction and windage are eliminated. A maximum blade effi-
ciency of 0.571 was obtained with nozzle K at a pressure ratio of 8
and a blade-jet speed ratio of 0.296 (fig. 4(a)). The blade effi-
ciency of nozzle K was equal to or higher than that obtained for
nozzle J over the range of operating variables investigated. These
results show a reversal of the trend indicated in reference 5. The
explanation of this reversal is beyond the scope of this report.
The maximum difference in blade efficiency was 0.040 at a pressure
ratio of 20 and a blade-jet speed ratio of 0.260 (fig. 4(c)), the
difference being negligible at a pressure ratio of 8 and the low
speeds (fig. 4(a)).

For all pressure ratios and all nozzle-rotor combinations
investigated, efficiency continuously increased with blade-jet
speed ratio. It was impossible to obtain a peak efficiency because
turbine speed was limited to the design value of 18,000 rpm. Effi-
ciency decreased with an increase in pressure ratio for any given
blade-jet speed ratio and for all nozzle-rotor combinations. Blade-
horsepower output is defined as brake-horsepower output plus windage
and mechanical losses. Because windage losses are a function of
rotor and blade configuration and mechanical losses are dependent
on the reduction-gear and bearing friction, these losses are for
the most part independent of nozzle design. The horsepower neces-
sary to overcome these losses for any specified inlet condition,
blade-jet speed ratio, and pressure ratio is the same for both
nozzles J and K. Crediting the turbine output with this incre-
mental horsepower does not result in equal increments of efficiency
(blade minus brake) for the two nozzles because the observed weight
flow for nozzle K is approximately 77 percent of that for nozzle J
at corresponding flow conditions; and efficiency is an expression
of horsepower per pound of air flow at the specified operating
conditions. This effect is noticeable when figures 2 and 4 are
compared. Although the maximum brake efficiencies are substan-
tially equal for the two nozzles at a pressure ratio of 8
(fig. 2(a)), the maximum blade efficiencies at corresponding
conditions (fig. 4(a)) differ by 0.020.

The blade efficiencies of the rotor having 20°-inlet-angle
blades with nozzles J and K are compared (fig. 5) with results
previously obtained at corresponding operating conditions with
nozzles A, E, H, and I (reference 4). The maximum variation in
efficiency was 0.040. The blade efficiency obtained with nozzle J
was generally lower than that obtained with the other nozzles.
The blade efficiency for nozzle K was equal to or higher than that

for the other nozzles at pressure ratios of 15 and 20 over the speed range investigated. At a pressure ratio of 8, the blade efficiency of nozzle K was exceeded by that obtained for nozzles I and A.

SUMMARY OF RESULTS

An investigation of a single-stage modification of the turbine from a Mark 25 aerial-torpedo power plant with two nozzle designs and 20°-inlet-angle blades produced the following results:
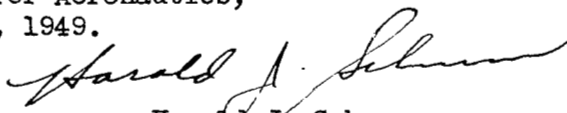
1. The blade efficiency of the unit with nozzle K was equal to or higher than that obtained with nozzle J over the range of operating variables investigated. The maximum blade efficiency of 0.570 was obtained with nozzle K at a pressure ratio of 8 and a blade-jet speed ratio of 0.296.
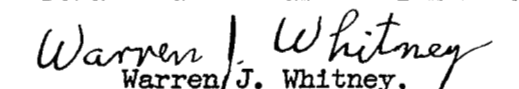
2. The difference in blade efficiency was negligible at a pressure ratio of 8 and the low speeds. The maximum difference in blade efficiency was 0.040 at a pressure ratio of 20 and a blade-jet speed ratio of 0.260.

3. The blade efficiency for nozzle J was relatively low compared with the nozzle designs previously investigated. At pressure ratios of 15 and 20, the blade efficiency for nozzle K was equal to or higher than those obtained with other nozzles.

4. The maximum difference in blade efficiency ascribable to the six nozzle designs in combination with the 20°-inlet-angle rotor blade was 0.040.

Lewis Flight Propulsion Laboratory,
    National Advisory Committee for Aeronautics,
        Cleveland, Ohio, May 10, 1949.

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1. Hoyt, Jack W., and Kottas, Harry: Investigation of Turbine of Mark 25 Torpedo Power Plant with Five Nozzle Designs. NACA RM SE7I03, Bur. Ord., 1947.

2. Hoyt, Jack W.: Investigation of Single-Stage Modified Turbine of Mark 25 Torpedo Power Plant. NACA RM SE7L15, Bur. Ord., 1948.

3. Hoyt, Jack W., and Kottas, Harry: Effect of Turbine Axial Nozzle-Wheel Clearance on Performance of Mark 25 Torpedo Power Plant. NACA RM SE8B04, Bur. Ord., 1948.

4. Schum, Harold J., and Hoyt, Jack W.: Effect of First-Stage Blade Design on Performance of Mark 25 Torpedo Power Plant. NACA RM SE9G20, Bur. Ord., 1949.

5. Schum, Harold J., and Whitney, Warren J.: Performance of Single-Stage Turbine of Mark 25 Torpedo Power Plant with Two Special Nozzles. I - Efficiency with 0.45-Inch Rotor Blades. NACA RM SE9G20a, Bur. Ord., 1949.

TABLE I - EFFICIENCY DATA FOR SINGLE-STAGE MODIFIED TURBINE WITH NOZZLE J AND 20°-INLET-ANGLE BLADES

[Inlet temperature, 1000° F; inlet pressure, 95 lb/sq in. gage]

| Pressure ratio	Air weight flow (lb/hr)	Fuel-air ratio	Horsepower available from isentropic expansion	Turbine speed (rpm)	Brake horsepower	Blade-jet speed ratio	Gas density in turbine case (lb/cu ft)	Brake efficiency	Rotor efficiency	Blade efficiency
8	935.0	0.0136	59.81	6,029	14.92	0.0977	0.0323	0.249	0.255	0.257
	934.2	.0136	59.76	8,112	18.87	.1315	.0328	.316	.326	.329
	934.2	.0136	59.76	10,135	22.21	.1643	.0331	.372	.387	.393
	934.2	.0136	59.76	12,138	24.80	.1967	.0330	.415	.435	.443
	934.2	.0136	59.76	14,181	26.82	.2298	.0327	.449	.474	.487
	933.3	.0135	59.70	16,204	28.36	.2626	.0324	.475	.505	.527
	933.3	.0135	59.70	18,247	29.10	.2957	.0320	.487	.523	.554
15	930.7	0.0137	71.88	6,069	15.52	0.0896	0.0168	0.216	0.220	0.222
	930.7	.0137	71.88	8,112	19.73	.1198	.0170	.275	.283	.285
	930.7	.0137	71.88	10,095	23.15	.1491	.0168	.322	.335	.338
	930.7	.0137	71.88	12,158	26.24	.1795	.0166	.365	.382	.385
	930.7	.0137	71.88	14,181	28.65	.2094	.0167	.399	.420	.424
	929.9	.0136	71.81	16,184	30.56	.2389	.0165	.426	.451	.459
	930.7	.0136	71.87	18,207	31.98	.2688	.0165	.445	.474	.487
20	930.7	0.0138	76.86	6,089	15.55	0.0870	0.0139	0.202	0.207	0.208
	930.7	.0138	76.86	8,092	19.52	.1156	.0142	.254	.262	.264
	930.7	.0138	76.86	10,115	23.17	.1445	.0139	.302	.313	.316
	930.7	.0138	76.86	12,138	26.36	.1733	.0136	.343	.359	.361
	930.7	.0137	76.85	14,161	28.93	.2022	.0137	.376	.396	.399
	930.7	.0137	76.85	16,194	31.22	.2313	.0136	.406	.430	.436
	930.7	.0137	76.84	18,207	32.70	.2600	.0136	.426	.453	.463

TABLE II - EFFICIENCY DATA FOR SINGLE-STAGE MODIFIED TURBINE WITH NOZZLE K AND 20°-INLET-ANGLE BLADES

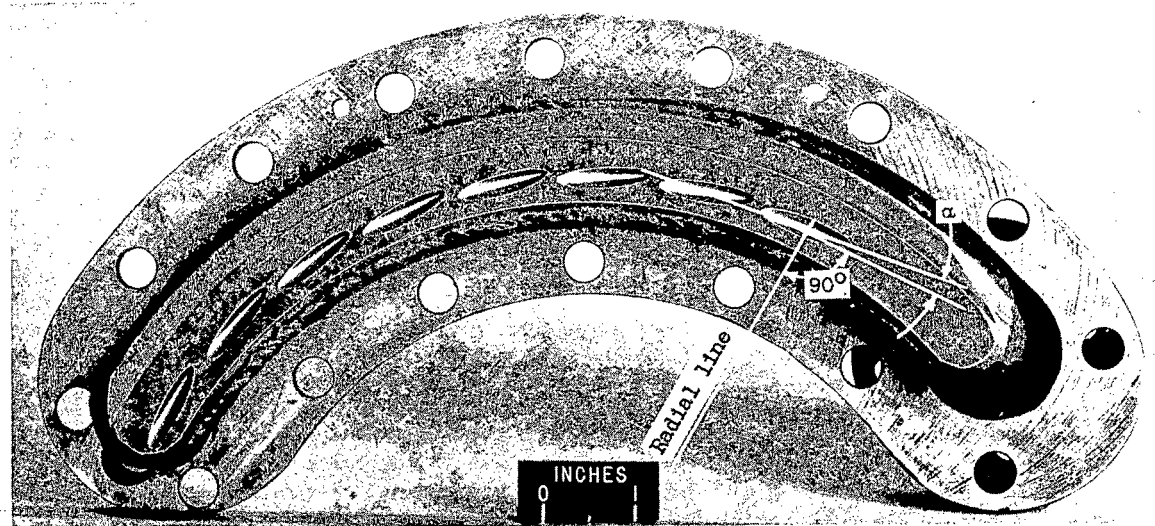[Inlet temperature, 1000° F; inlet pressure, 95 lb/sq in. gage]

Pressure ratio	Air weight flow (lb/hr)	Fuel-air ratio	Horsepower available from isentropic expansion	Turbine speed (rpm)	Brake horse-power	Blade-jet speed ratio	Gas density in turbine case (lb/cu ft)	Brake effi-ciency	Rotor effi-ciency	Blade effi-ciency
8	724.8	0.0142	46.41	6,049	11.44	0.0980	0.0329	0.247	0.253	0.256
	724.8	.0142	46.41	8,092	14.40	.1311	.0330	.310	.323	.328
	724.8	.0141	46.40	10,115	17.13	.1639	.0342	.369	.389	.396
	724.8	.0142	46.41	12,158	19.43	.1970	.0349	.419	.445	.456
	724.1	.0141	46.35	14,201	20.78	.2301	.0354	.448	.481	.500
	724.1	.0141	46.35	16,184	21.92	.2623	.0349	.473	.512	.542
	723.4	.0141	46.31	18,247	22.31	.2957	.0347	.482	.528	.571
15	724.8	0.0142	56.02	6,089	12.44	0.0899	0.0180	0.222	0.228	0.230
	724.8	.0142	56.02	8,092	15.76	.1195	.0181	.281	.292	.295
	724.8	.0142	56.01	10,166	18.83	.1501	.0183	.336	.353	.357
	724.8	.0142	56.01	12,118	21.36	.1789	.0187	.381	.403	.407
	724.8	.0142	56.01	14,161	23.47	.2091	.0190	.419	.446	.453
	724.8	.0142	56.02	16,224	25.13	.2396	.0191	.449	.481	.493
	724.8	.0142	56.01	18,207	26.28	.2688	.0191	.469	.507	.526
20	723.4	0.0141	59.76	6,069	12.48	0.0867	0.0136	0.209	0.214	0.216
	722.8	.0141	59.71	8,092	15.92	.1156	.0138	.267	.277	.279
	722.8	.0141	59.71	10,115	19.00	.1445	.0140	.318	.333	.337
	722.8	.0141	59.71	12,138	21.68	.1733	.0140	.363	.383	.386
	722.8	.0141	59.71	14,201	23.91	.2028	.0142	.400	.426	.430
	722.8	.0141	59.71	16,184	25.87	.2311	.0143	.433	.464	.472
	722.8	.0141	59.71	18,227	27.15	.2603	.0143	.455	.490	.503
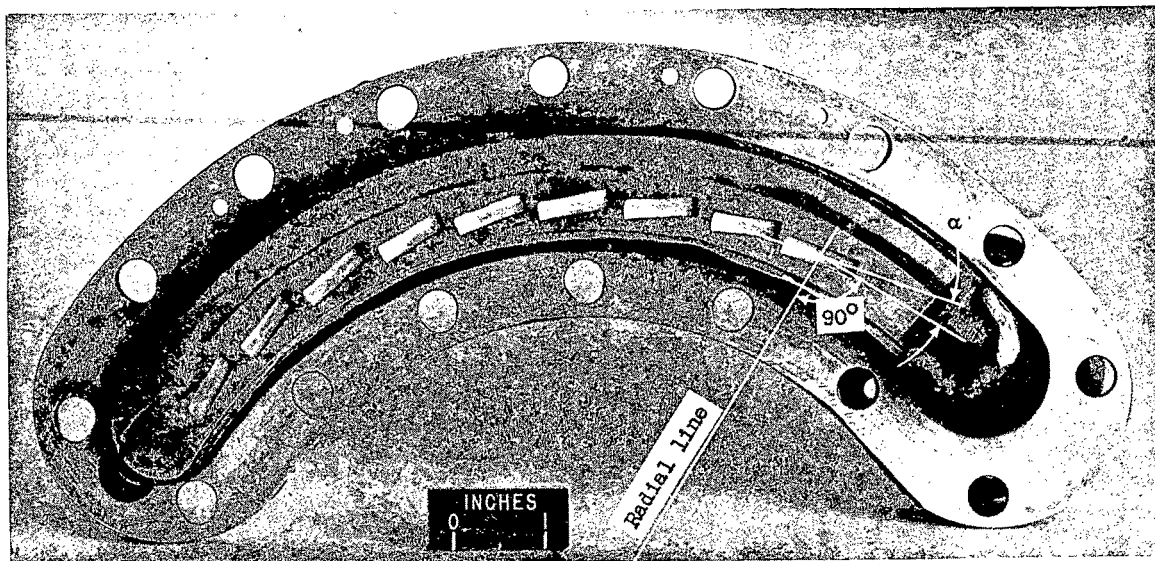
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(a) Nozzle J; angle of intangency α, 9°.

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(b) Nozzle K; angle of intangency α, 6°.
Figure 1. - Nozzle assembly showing outlet side.

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(a) Pressure ratio, 8.

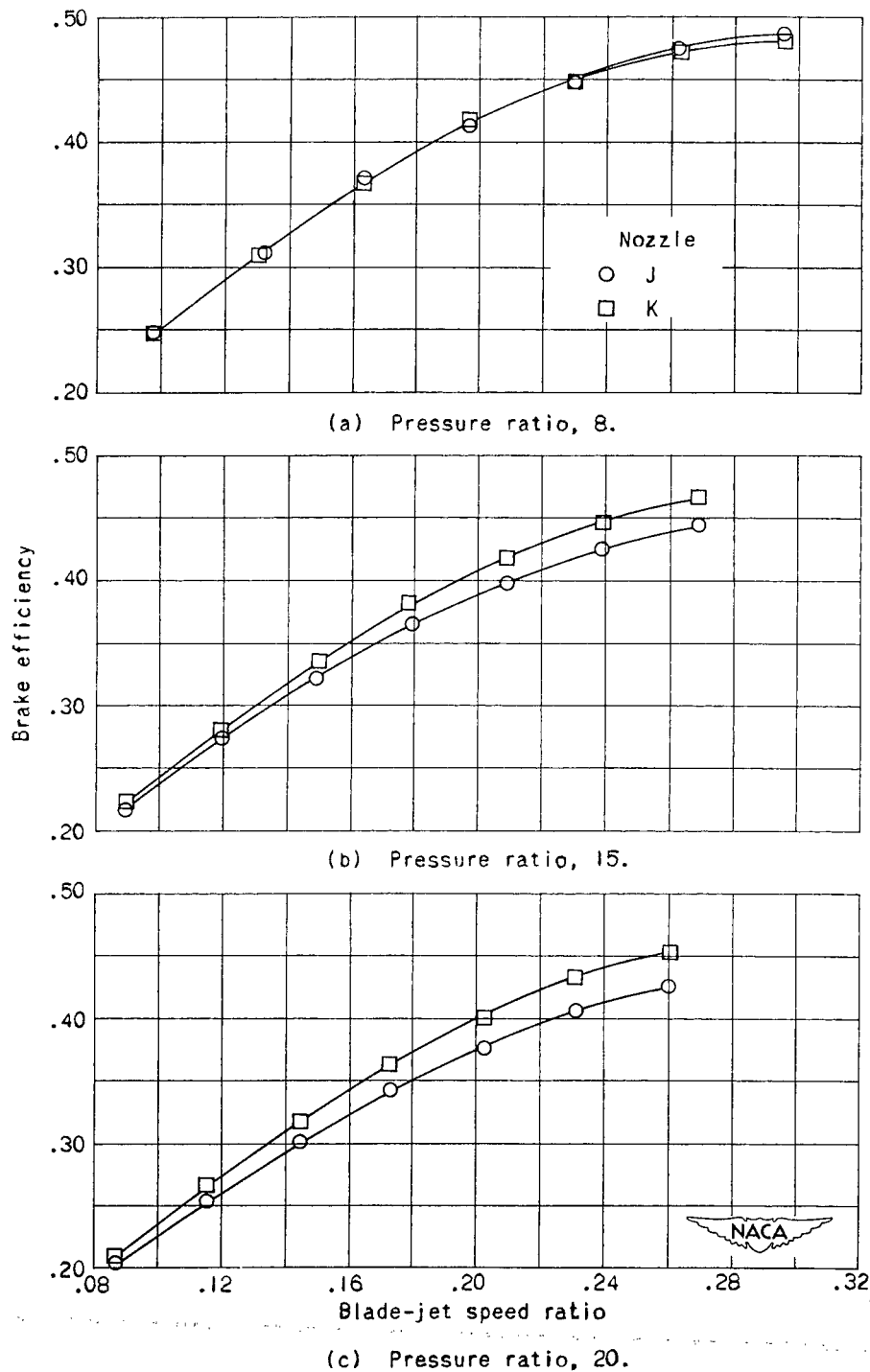(b) Pressure ratio, 15.

(c) Pressure ratio, 20.

Figure 2. - Variation of brake efficiency with blade-jet speed
    ratio for single-stage modified Mark 25 torpedo turbine with
    nozzles J and K in combination with special 20°-inlet-angle
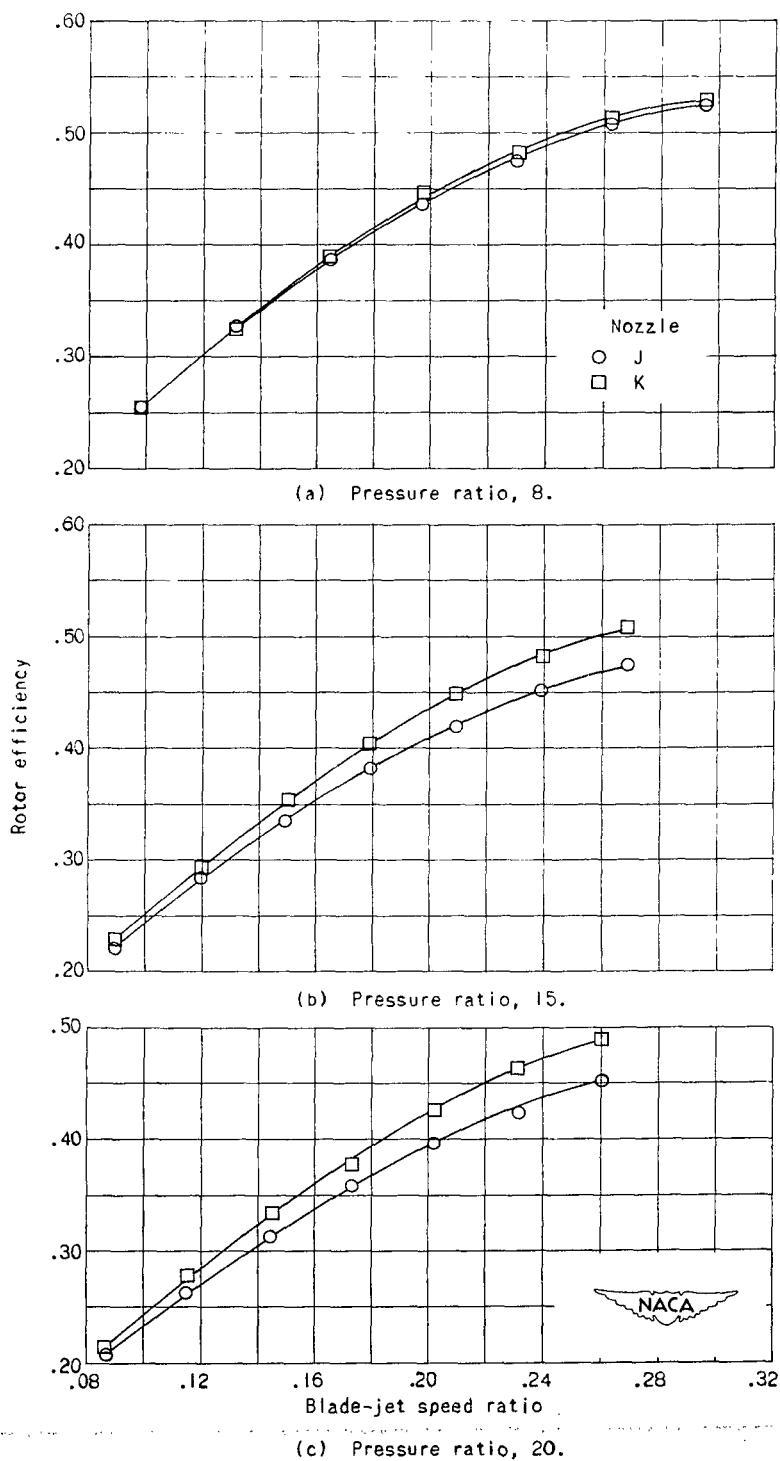   blades.

(a) Pressure ratio, 8.

(b) Pressure ratio, 15.

(c) Pressure ratio, 20.

Figure 3. - Variation of rotor efficiency with blade-jet speed
  ratio for single-stage modified Mark 25 torpedo turbine with
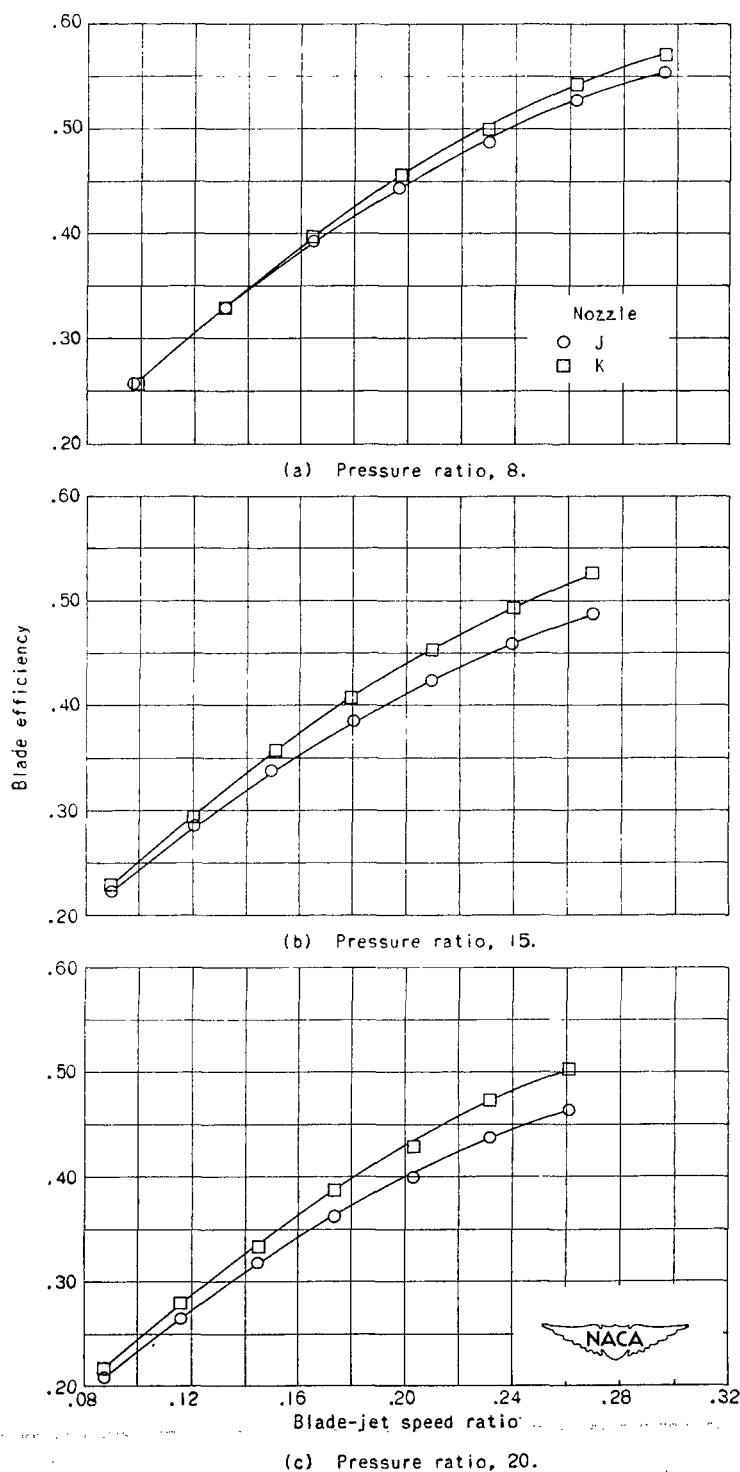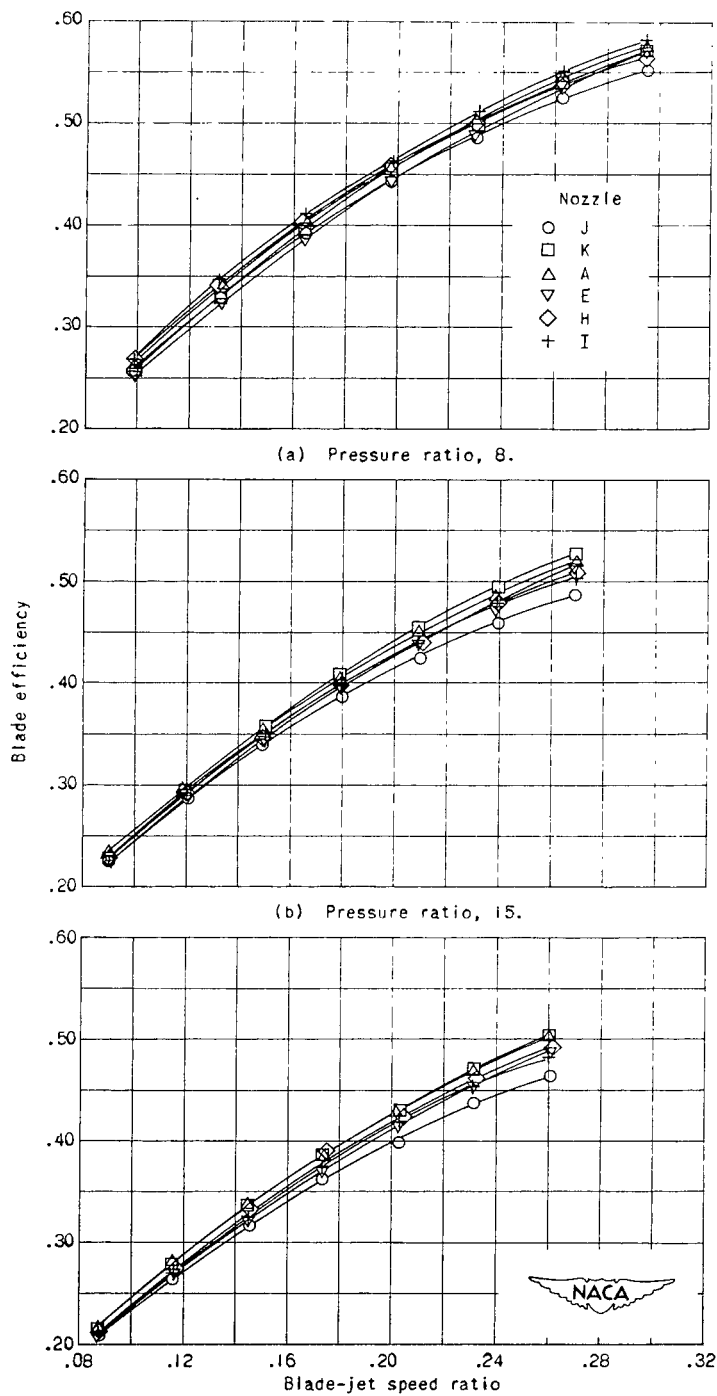 nozzles J and K in combination with special 20°-inlet-angle
  blades.

(a) Pressure ratio, 8.

(b) Pressure ratio, 15.

(c) Pressure ratio, 20.

Figure 4. – Variation of blade efficiency with blade-jet speed
ratio for single-stage modified Mark 25 torpedo turbine with
nozzles J and K in combination with special 20°-inlet-angle
blades.

(a) Pressure ratio, 8.

(b) Pressure ratio, 15.

(c) Pressure ratio, 20. (Data for nozzle H were obtained at
pressure ratio of 19.)

Figure 5. – Variation of blade efficiency with blade-jet speed
ratio for single-stage modified Mark 25 torpedo turbine with
nozzles J, K, A, E, H, and I in combination with special
20°-inlet-angle blades. (Data for nozzles A, E, H, and I
obtained from reference 4.)